IOSR Journal of Applied Chemistry (IOSR-JAC)
e-ISSN: 2278-5736.Volume 13, Issue 6 Ser. I (June. 2020), PP 01-07
www.iosrjournals.org

Research of Heat Accumulation Capacity Binary Water Systems

Demchenko V.G., Konyk A.V.
Laboratory of processes and technologies of heat supply, Institute of Engineering Thermophysics of NAS of Ukraine
2a, Marii Kapnist Str., Kyiv, 03057, Ukraine

Abstract: *The article is devoted to the research of binary water systems with the purpose of their further use as a coolant and heat storage material (HSM) in capacitive type heat accumulators. A method is presented for engineering calculation, which allows to determine the volume and functional feasibility of the battery, the maximum amount of stored heat, as well as to conduct a comparative analysis of different combinations of HSM. The results of researches of receiving useful heat in time, and depending on temperature, and also energy efficiency are resulted.*

***Background**: The search is a relevant area of research for new and the research of already known HSM in the field of energy and heat supply. It is known that HSMs differ in application temperature, physical condition, origin, field of application, economic feasibility, and so on. One of the promising areas is the use of binary water systems as low-temperature HSM in heat accumulators.*

***Materials and Methods**: Based on the analysis of literature sources, binary water systems based on water-soluble polymers (WSP) in a mixture with antifreeze of natural origin were selected for research. Water was selected as a control sample. An experimental stand based on a pipe-in-pipe heat exchanger was created for research.*

***Results**: As a result of research, the effect on energy efficiency as HSM and as a coolant in the circulation circuit of binary water systems with WSP in different combinations was established. High stability of thermal indicators of binary water systems with WSP and antifreeze at repeated thermal cycle is noted. The combination of mineralized aqueous solution of antifreeze with a mixture of water-soluble polymers has the best thermal characteristics. In addition, it was noted that adding WSP solution to the water circuit of the coolant circulation increases fuel efficiency by 7%, and the overall effect was 14%, when using WSP also in the heat accumulator, compared to water.*

***Conclusion:** As a result of a series of experiments, it was found that during the ten thermocycles, the thermo-physical parameters of water with the addition of 1% WSP and the binary system of an aqueous solution of antifreeze remained stable. The maximum amount of stored heat in time and at the same temperature, when charging, showed a mixture of an aqueous solution of antifreeze with the addition of 1% WSP. The heating rate of the aqueous solution with WSP is the fastest and exceeds that for the aqueous solution of antifreeze by almost 2 times, which suggests that the addition of WSP significantly improves the heat transfer coefficient of the binary system. In addition, the use of aqueous WSP solution as a coolant in the heating circuit is more efficient than water and aqueous antifreeze solution. As a result, when using an aqueous solution with the addition of WSP, the highest efficiency of the heat accumulator was obtained.*

***Key Word:** binary water systems, heat accumulating substances, water-soluble polymers, heat accumulator, efficiency.*

Date of Submission: 06-06-2020 Date of Acceptance: 22-06-2020

I. Introduction

Today the world is reforming the heating system. Countries with developed economies are moving to an energy-efficient 4th generation heating system, the so-called 4G. The main characteristics of 4G are: lowering the coolant temperature to + 50… 60℃, application of new technologies in the creation of heat accumulators and the use of main pipelines to supply heat to consumers in winter and cold for central air conditioning - in summer, with extensive involvement of renewable generation sources. Leaders in this area of work are countries such as the United States, China, Japan and some European countries. The modern district heating system in Ukraine needs conceptual changes and modernization. The system is in transition between 2G and 3G, however, it can be adapted and integrated into the 4G system in a short time [1-3]. In the last decade, research work on the development of ecological sources of wind, solar and geothermal energy has been actively conducted and implemented in the world. However, it should be noted that these sources are widely used in the private sector and by owners of private enterprises, but not in the heating systems of urban agglomerations.

The authors of the article propose a new approach to building a system of heat and cold supply by using a mobile heat accumulator will allow to organize a discrete process of heat supply and cooling of objects and individual buildings.

The main element of such a system is a capacitive type heat accumulator filled with specially selected HSM for low-temperature heating systems in winter and cooling in summer. Mobile heat accumulators will be used both in future stationary 4G systems and for emergency heat supply of settlements, in disaster zones, in case of emergencies. Since the use of mobile heat accumulators is planned, mainly at negative ambient temperatures, it is very important to find HSM substances with maximum heat storage capacity.

In the laboratory of processes and technologies of heat supply of the Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine the concept of discrete heating system is developed and the experimental stand on which HSM researches are carried out is created. Developments are aimed at creating low-temperature heat and cold batteries [4, 5].

This article presents the results of research to determine the efficiency of heat transfer and storage capacity of binary water systems depending on the composition of the liquid in the heating and cooling circulation system and in the volume of the accumulator.

II. Material and Methods

Object of research

The object of research is binary water systems. The aim of the study is to determine the optimal composition of the combination of aqueous solutions and their storage capacity for further use in low-temperature capacitive heat accumulators.

As a result of the analysis of literature sources for experimental studies, the following substances were selected, namely: a mixture of water-soluble polymers WSP, natural antifreeze and water [6, 7].

When choosing the heat-accumulating substances HSM, the authors gave preference to liquids that provide the highest reliability of functionality. The coolant must have stable physical and chemical properties during thermal cycling, be corrosion resistant, resistant to overheating and supercooling, economically feasible and environmentally friendly. The research was conducted in three stages.

At the first stage was analyzed the experimental calculation method the specific heat of aqueous antifreeze solutions with the addition of WSP as a heat carrier and a comparison was conducted with water .

In the second stage was conducted the work, using a laboratory stand, a study of the impact of WSP on the efficiency of heating energy.

In the third stage was conducted a research of the dependence of the amount of stored heat over time and on the heating temperature of the HSM heat accumulator.

The following liquids were used for research:

1. water (HSM 1) meets the standards set out in [8]. Control HSM;
2. binary water system with 33% aqueous solution of antifreeze (HSM 2). For research was used mass-produced antifreeze brand "Defreeze". Defreeze is an aqueous-mineral solution obtained from natural magnesium chloride hexahydrate ($MgCl_2$ $6H_2O$) and contains organic stabilizers, nanoinhibitors for corrosion protection, distilled or deionized water;
3. binary water system (HSM 3): 70% water + 29% defreeze + 1% WSP;
4. binary aqueous system (HSM 4): water with the addition of 1% WSP is an aqueous solution of natural polysaccharides with cellulose esters of plant origin. WSP has stable properties in a wide range of temperatures (from -18ºC to 120ºC) and acidity (from 2 to 12pH). Researches have shown that these unique in rheological properties of liquids in solutions of high-density salts are able in a certain temperature range not to reduce, and in some saline solutions even increase the effective viscosity of solutions with increasing temperature.

The calculations were performed according to the known method allows to determine the volume and functional capacity of the heat accumulator, the maximum amount of heat stored and to perform a comparative analysis of HSM [9].

The amount of useful heat emitted from the battery is calculated according to the methods selected for each individual heat source. The approach is different when using solar energy, waste heat, creating heat reserves to cover peak loads, etc. In cold accumulators, cold storage is useful. If the process is carried out at constant pressure, then the amount of stored heat Qs is constant and equal to the enthalpy of matter. The classical approach to heat load calculations is carried out according to the formula:

$$Q_s = m\, c_p\, \Delta T = \rho\, V\, c_p\, \Delta T \qquad (1)$$

where: Q_s – the amount of stored heat (J); c_p – average specific heat of the substance [J / kg K]; ρ - the density of the solution [kg / m³]; V·- volume of accumulative substance [m³]; ΔT– temperature difference at the inlet and outlet of the circulation circuit of heating / cooling of the heat carrier [°C]; m – mass of substance HSM [kg].

The amount of stored heat is directly proportional to the mass and volume of the HSM, the temperature of charging and discharging the battery, the heat capacity and the density of the accumulating liquid. Therefore, increasing the efficiency of the heat accumulator can be achieved by influencing these parameters.

Increasing the volume and weight of the battery is not economically feasible. Increasing the charge temperature and decreasing the discharge temperature is technologically impossible. WSP changes the viscosity of the coolant, which allows you to get better contact of the liquid HSM with the heat transfer surface, which significantly increases the efficiency of the heat accumulator.

A more informative indicator is the specific heat Q_y [J / kg] is a constant value for a particular substance :

$$Q_y = Q_s / m \quad (2)$$

Since heat loss depends on the temperature difference between the heat accumulator and the environment, an important factor is the speed at which the accumulator can be cooled, which is a function of thermal diffusion. In addition, the thermal conductivity of the HSM significantly affects the charging and discharging time and the rate of heat retention. [10]. When we used as HSM aqueous solutions, in the absence of stratification in the volume of the heat accumulator, the energy balance in the tank is as follows:

$$m\ c_p\ dt_s / dr = Q_u - Q_l - k_s\ \Delta T \quad (3)$$

де: Q_u і Q_l - heat of energy transformation from heat source to HSM [J]; k_s – the heat loss coefficient of the tank depends on the surface area of the heat accumulator.

Stratification negatively affects the amount of useful heat can be obtained from the heat accumulator, reducing it by about 25… 30%. The required reserve of thermal energy is selected based on software the reliability, the possibility of compensation for unforeseen interruptions in energy supply, the availability or planning of backup sources, cost limits, etc., and is taken at the level of 70… 80% of Q_s.

If the temperature of the HSM is known, other temperature-dependent parameters can be estimated [11]. Equation (3) can be used to determine T_s - the temperature of the binary water system HSM as a function of time.

$$T_s = T_1 + \Delta\tau / m\ c_p\ [Q_u - Q_l - k_s\ \Delta T] \quad (4)$$

Where: τ - time [min.].

An important factor is the energy efficiency of the storage system. High efficiency is achieved by system power, full energy use and reduced fuel consumption for heating HSM.

In the General case, the efficiency of the storage system can be defined as the ratio of the amount of heat received Q_u to the amount of energy spent on its production (N):

$$\eta_s = Q_u / N \quad (5)$$

The presented calculated dependences are confirmed by the obtained experimental data and can be used in the design and selection of the optimal mode of operation of the heat accumulator. The considered technique is rather simple, but there is a probability to receive result with a considerable error therefore the resulted calculation can be used only as engineering.

Description of the experimental stand.

To conduct research, a model of heat accumulator (further - stand) was developed, which is designed for a complex experimental research of thermophysics and heat accumulation properties of HSM [4].

The stand consists of an electric boiler with a power regulator (1), a model of a heat accumulator in the form of a heat exchange device such as "pipe in a pipe" (2), a circulating pump with a thyristor engine speed control system (3), a buffer tank (4), valve (5), flow regulator (6), coolant cooling radiator (7), thermomanometer (8), mechanical water flow meter (9), expansion tank to maintain the set pressure in the coolant circulation system (10), drainage (11), electricity consumption meter (12), measuring concentrator with thermocouples (13), computer with remote webcam (14) and water supply and power supply systems that ensure stable operation of the heat accumulator model. The scheme of the stand is shown in Figure 1.

Researches are conducted in the temperature range from 50 to 100°C. Heat supply and removal from the heat exchange device (2) is carried out by means of the heat carrier circulating in the circulation system. The speed of the coolant in the system is within 0,03…0,2 l/s (108…720 l/ hour).

The heat accumulator model is a pipe-in-pipe heat exchanger, where the main element is a heat-insulated metal pipe with a diameter of 200 mm and a length of 1000 mm located spiral ribbed pipe a diameter of 32 mm, through which the coolant circulates. The intertube space is filled with the investigated HSM, through the holes in which thermocouples are installed.

The heat carrier is heated by an electric boiler, the circulation is provided by a pump, and the cooling circuit is a radiator. During the experiment, the meters record the thermal and electrical power, and thermo-couples - the temperature of the heat carrier in the circulation circuit.

The coolant temperature is regulated by the boiler control unit, the coolant speed is carried out by the engine speed thyristor, the coolant flow is carried out by the balancing valve.

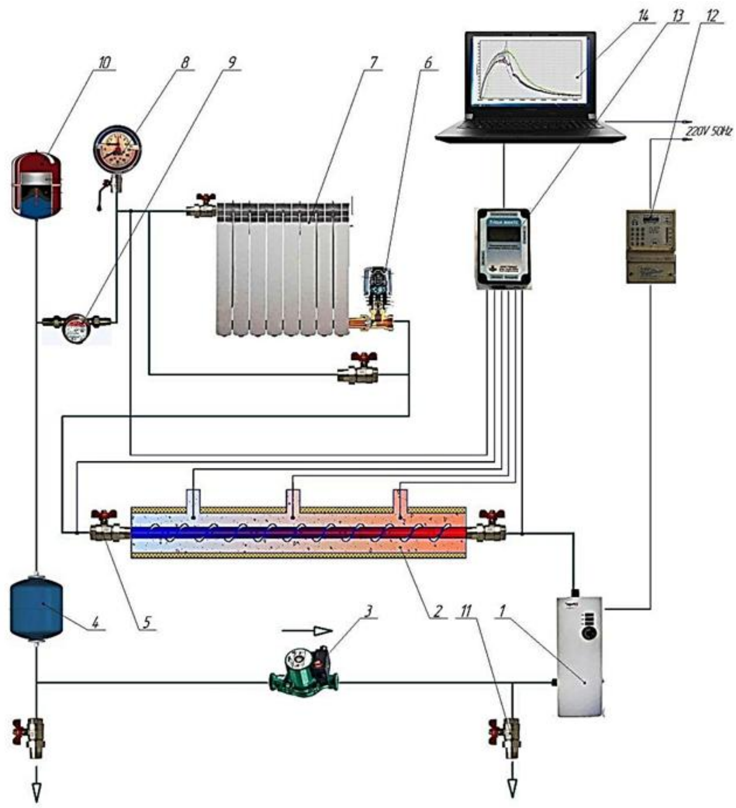

Figure 1: Scheme of the experimental stand of the heat accumulator model

III. Research methods

Preliminary theoretical researcehes of the heat transfer process during heating and cooling of the battery model were performed using mathematical modeling. To determine the possible change in temperature and enthalpy of HSM when working in the battery model, the method of cyclic thermal analysis was used. The essence of the method is the thermal cycling of the samples in a given temperature range in automatic mode, ie the investigated HSM are subjected to repeated cyclic heating and cooling. Temperature control was performed using differentially included thermocouples according to the method described in [12].

The tests were performed in a room with a stable temperature at a lower ambient temperature than the operating temperature of the coolant. The circulating pump provides flow parameters in the design mode. Temperature data is recorded by an analog-to-digital converter and displayed as a diagram on a computer. The values of the coolant flow in the circulation system are transmitted to the flow meter. The values of electricity consumption for heating the coolant are recorded by the meter.

To perform further calculations to determine the accumulated amount of heat, thermocouples are installed along the length of the heat exchanger at the inlet, outlet and in the center of the battery, the indicators of which are recorded by the measurement concentrator. The mass of the HSM and the volume of the coolant in the circulation system are pre-determined by the volume and density of the liquid.

HSM 1 was used as a heat carrier in the heating and cooling system of the heat accumulator model. The test consists of determining the volume of the HSM and at least three cycles of measuring the temperature of the heat carrier at the radiator outlet and inlet and in the heat accumulator model. After the end of heating and switching off of an electric copper, values of temperature at cooling of HSM are fixed, circulation of the heat carrier, at the same time, does not stop.

The results of the research are presented in Figures 2, 3, 4, 5.

IV. Result

In the first stage of the research, the specific heat Q_y [J / kg] was established for the coolant HSM 1, HSM 2 and HSM 3. According to formulas (1) and (2), calculations were performed the masses of coolant in the same volume were previously experimentally determined. Reference data were used and samples were weighed. The results are presented in Figure 2.

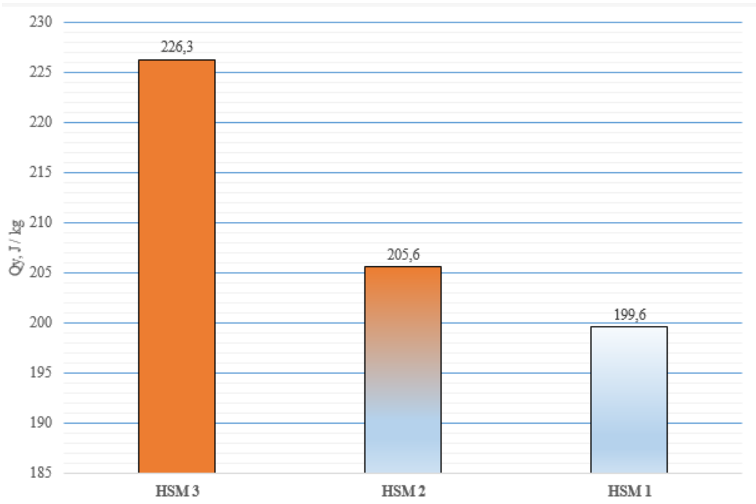

Figure 2: Specific heat Q_y of binary water systems HSM 1, HSM 2 and HSM 3

Experimental researches show that the addition of defreeze improves the specific heat compared to water by 3,0%, and the subsequent addition of WSP increases Q_y by almost 12%.
To verify the results of the calculations, a laboratory research of the effect of adding an aqueous solution of 1% WSP on the efficiency of heat accumulation and reducing the consumption of electricity for heating the coolant and HSM. The results are shown in Figure 3.

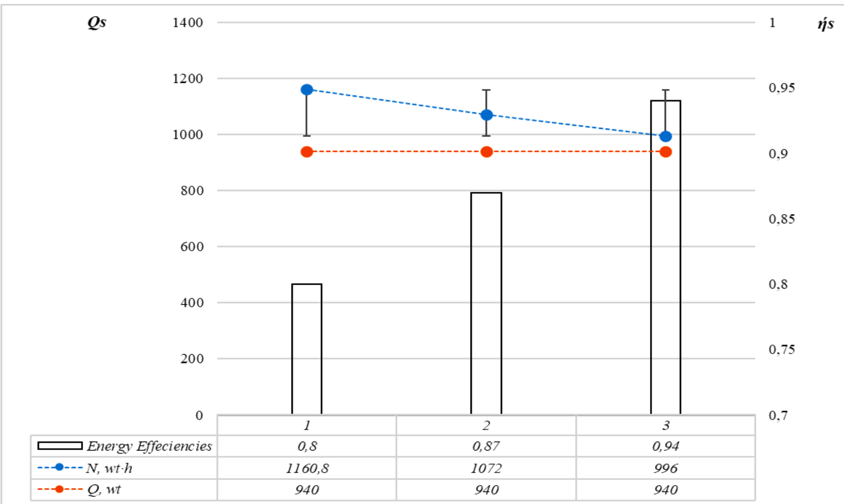

Figure 3: The effect of adding an aqueous solution of 1% WSP on the efficiency of the heat accumulator and the properties of the coolant, where: 1 - water, 2 - water with WSP (HSM 4), and 3 - HCM 4 in the circulation circuit of the coolant and heat accumulator

The research was conducted on an experimental stand (Fig. 1). According to the meters, the consumption of electricity for the production of the same amount of heat, which was measured by a heat meter was compared.

Calculations for heat load are carried out according to formula (1), verification of the obtained results was performed by analytical calculations according to formula (3), calculation of efficiency according to formula (5). As can be seen, the addition of an aqueous solution of WSP in an amount of 1% of the total volume leads to a reduction in electricity consumption for heating the coolant by 7% and increases the efficiency of the storage system by a total of 14%.

During the third stage of research, the dependences of the amount of stored heat Q_s over time in the capacity of the heat accumulator model and the dependence of the amount of stored heat Q_s on temperature were obtained. HSM 4 was used as a heat carrier in the heating circuit.

Functions for describing mathematical models can be given both analytically and tabularly, in which the function is known only at certain discrete values of the argument. Functional dependencies obtained as a result of calculations are given in a tabular way.

The analysis of the obtained results was performed by determining the slope of the line used to approximate the data by linear regression. The slope coefficient is equal to the tangent of the angle between the straight and positive directions of the y-axis. To determine the slope, use any two points on the line. In this case, the fraction of the division of the length of the segment obtained by projecting these two points on the y-axis is calculated, namely on the length of the segment formed by the projections of the same two points on the abscissa. If the value of the coefficient is known, it is possible to calculate the rate of change of data along the regression line.

Figure 4 shows the dependence of the amount of stored heat in the battery depending on the charging time. As you can see, the lowest performance is water - HSM 1, and the highest result - HSM 3. Adding 1% WSP to the binary system water-freeze significantly increases the heat storage capacity of the system. Substance HSM 2 occupies an intermediate position.

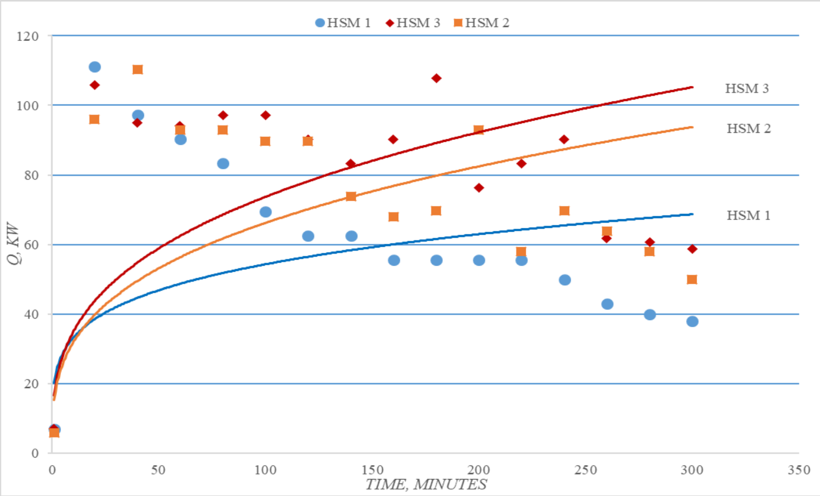

Figure 4: The amount of stored heat HA depending on the charging time

Figure 5 shows the dependencies of the amount of stored heat Q_s on temperature. Here also the best results are inherent in the HSM 3 system.

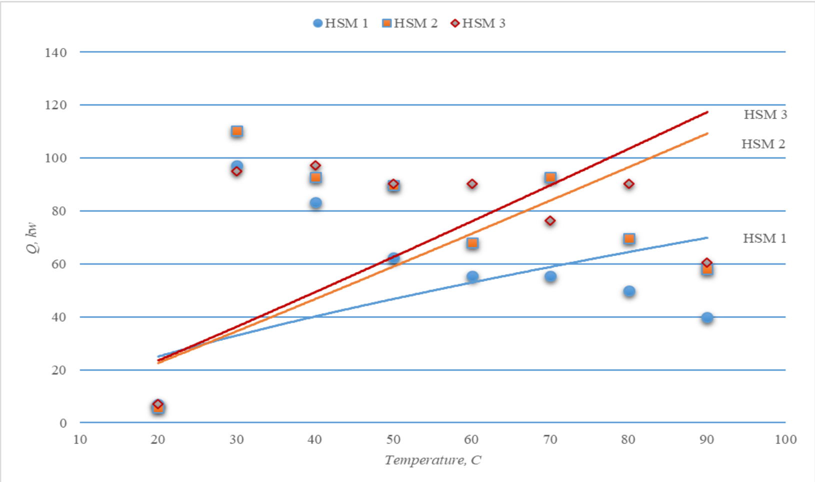

Figure 5: Dependence of the amount of stored heat on temperature

It should be noted that with the highest probability R^2 = 0,7… 0,9, the process of temperature set rate and the dependence of the amount of stored heat on the coolant temperature at the lowest energy consumption is best described by the power function of the form $Y = aX^n$. It can be concluded that the specific heat, the rate of accumulation and the amount of stored thermal energy depends on the density of the solution of the binary water system, and is regulated by the addition of water-soluble polymers.

V. Discussion

The specific heat, which is a constant value, for binary water systems HSM 1, HSM 2 and HSM 3 increases significantly with the addition of water-soluble polymers. According to the authors, this is due to the transformation of an aqueous solution into a pseudoplastic fluid. During the ten thermal cycles HSM 2, HSM 3 and HSM 4, the thermo-physical temperature indicators remained stable. This indicates that the composition of the coolant is selected correctly.

During a series of experiments it was found that the heating process (up to 90°C) using HSM 3 as a coolant is the fastest and most cost-effective compared to water and liquid HSM 2. It was found that the heating rate (up to 90°C) in NSM 3 is the fastest and exceeds that for HSM 2 by almost 25%, which suggests that the addition of WSP improves the value of the heat transfer coefficient. Adding only 1% WSP to the binary water system significantly increases the heat storage capacity of the system as a whole. When using an aqueous solution with the addition of WSP, the highest efficiency of the heat accumulator was obtained in comparison with water and antifreeze. This reduced electricity consumption by 7% when using HSM as a heat carrier and by 14% when adding WSP to the heat accumulator volume.

The use of binary water systems as a coolant and energy-saving material opens up significant prospects. It should be noted that the problems of creating binary water systems, the study of their properties to date have been little studied and require further work in this direction.

VI. Conclusion

Thermal energy storage is a technology that works by obtaining, accumulating and delivering heat lots for further use. It can be used for heating, cooling, electricity manufacturing and industrial technologies. Most research focuses on materials for heat storage, and the research of heat carriers in different temperature ranges, the development of containers and heat insulation materials.

Storage systems need further work in the field of research. For example, in the field of improvement of water heat carriers and water heat storage systems for their integration into energy efficient heat supply of the 4G system. This is especially important for countries with a high level of district heating. The conducting of research of the heat accumulation capacity of binary water systems demonstrates the high potential of their use as a new generation of heat carriers and heat storage materials that can be created on their basis.

The use of naturals antifreeze and water-soluble polymers in quality impurities in water allows to obtain significant opportunities to save fuel and energy resources and have a high prospect of use of supply systems of heat and cold.

References

[1]. Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J. E., Hvelplund, F., et al. (2014). 4th Generation District Heating (4GDH): integrating smart thermal grids into future sustainable energy systems. Energy 68, 1–11. doi: 10.1016/j.energy.2014.02.089

[2]. Process Intensification Principles Applied to Thermal Energy Storage Systems—A Brief Review, Xiaofeng Guo and imageAlain Pascal Goumba, review article, Front. Energy Res., 20 March 2018, | https://doi.org/10.3389/fenrg.2018.00017

[3]. https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge

[4]. Паспорт «Експериментальний стенд №5 для дослідження теплофізичних властивостей акумулюючих речовин та ефектів високотемпературної сорбції/десорбції», - НАНУ ІТТФ. - 2019р. – 28с.

[5]. VG Demchenko, VY Falco, Experimental research of thermal stability of substances for thermal energy storage Thermophysics and Thermal Power Engineering, 2019, 41 (2), p. 64-71

[6]. Демченко В.Г., Фалько В.Ю., Експериментальне дослідження термічної стійкості речовин для зберігання теплової енергії, Теплофізика та теплоенергетика, 2019, Т. 41, №2

[7]. Research of thermal cycling of organic substances with phase transition, Demchenko V.G., Tselen B.J., Konyk A.V., Ivanov S.O., 2020, «Scientific discussion» (Praha, Czech Republic), 1, 41, p. 54-58

[8]. ДСТУ 7525:2014 Вода питна. Вимоги та методи контролювання якості.

[9]. Construction calculation of mobile heat storage, VG Demchenko, SS Gron, ND Pogorelova, 2019, Thermophysics and Thermal Power Engineering, 41 (4), p. 35-43

[10]. Shah YT, editor. Thermal Energy: Sources, Recovery, and Applications. Boca Raton, FL, USA: CRC Press; 2018

[11]. Sarbu I. A comprehensive review of thermal energy storage. Sustainability.2018;10(2):191

[12]. Mobile accumulators for discrete systems heat-cold supplies. Part 1, Demchenko V.G., Falko V.J., 2018, Промислова теплотехніка, 40 (2), p. 20-27

Demchenko V.G,et. al. "Research Of Heat Accumulation Capacity Binary Water Systems." *IOSR Journal of Applied Chemistry (IOSR-JAC)*, 13(6), (2020): pp 01-07.